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Systems thinking for sustainable textiles in the automotive sector.

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Abstract
According to Messe Frankfurt (2013), recycled and renewable raw materials are two main drivers in the growth of the Mobiletech markets which accounts for about 22% of the technical textiles base. However, the use of recycled textiles for consumer facing textiles within automobiles (such as car seat coverings or interior linings) appears to remain a complex issue; the core reason stated being the increased cost, even though the textiles are very similar to that produced from virgin polyester fibres.

Studies have examined how sustainability has been incorporated into the automotive supply chain management at Volkswagen (Koplin et al.2007) and the optimization of the environmental compatibility of purchased goods such as 'product-based green supply' (Vermeulen et al. 2011), the importance of the consumer has also been acknowledged as a very influential driver to sustainable textile design (Diabat et al. 2014).

This paper considers the progress that has been made to date in developing consumer facing sustainable textiles solutions for the automotive textiles sector. By examining the complexities regarding the design and use of sustainable textiles solutions such as recycled textiles or non-adhesive lamination within the automotive supply chain, we consider what needs to be done further to develop a sustainable approach to the automotive textile design system.

Methods:
The paper reviews the current state of sustainable textile solutions for the automotive sector, in particular the recycling of polyester to highlight how the processes of recycled polyester and sustainable textiles production are linked in the system of automotive sector. A case study with Sage AI (UK) outlines and examines their design, development and manufacture process for exterior textiles (ie for car seat coverings and interiors). Using content analysis of the interviews, company literature, textiles manufacturing literature and Integration Definition for Function Modelling, we created diagrams of the process which were validated by the Design Director at Sage AI UK. These diagrams and literature review are examined from a systems perspective to identify potential feedback loops and leverage points to effect change and how the process could divert waste from disposal.

Results:
The paper will present IDEFO diagrams of each stage of the design process, highlighting some of the issues regarding the process and a table outlining the decision making around the use of recycled textiles. The paper will also outline the system that textile design for the automotive sector operates within. The interviews found that, although Sage AI headquarters provide worldwide trends information to all Sage locations, the OEM's concern regarding consumer knowledge within the EU markets; limited the greater use of recycled or non-adhesive laminated textiles the most sustainable textiles solutions, in favour of achieving lowest cost.

Discussion:
This study demonstrates how the design for automotive textiles is part of a system. Decisions around developing sustainable textiles solutions are through negotiation with the lead firm, the OEM that is seeking to manufacture the model. The automotive sector currently has governmental policy drivers for sustainability. Material stocks and flows and technology is also currently available for recyclable and sustainable textiles for the automotive sector. Although textiles recycling is an established practice and industry a number of issues are raised from this study that are common to areas such as fashion, home interiors and automotive. This need to be addressed such as marketing approaches for the recycled textiles, consumer knowledge about their uptake of recycled textiles, market development for recycled textiles products.

Key words: textiles, sustainable, recycled, systems

Introduction
The automotive industry is the subject of much research, it is the largest manufacturing activity, there is a complex supply chain, is resource intensive and emits various hazardous gases and waste products. This sector is also legally bound to deliver certain waste reduction targets set by the EU. As the manufacture and retailing of

automobiles continues to rise, so too does the number of end of life vehicles. This presents a challenge to the industry. This paper is structured as follows:
Section 1: literature review about systems thinking and the design process, sustainability within the automotive industry and textiles within the automotive industry
Section 2: research methods used to examine the consumer facing textiles design process at Sage AI (UK) their
Section 3: the research data
Section 4: discussion about the issues arising
Section 5: conclusions and proposition of new links to consider for the system of designing sustainable consumer facing automotive textiles.

1.1 Systems thinking and the design process

The General Systems Theory, first introduced as a theoretical framework for the study of biological development philosophies by Bertalanffy in the 1950's, became applied to study organisations, management, engineering, economics and system dynamics etc, because it enabled study of individual behaviour within the environmental contexts (Bertalanffy, 1950, Forrester, 1976). Systems have been described as "a set of things – people, cells, molecules, or whatever – interconnected in such a way that they produce their own pattern of behaviour over time." (Meadows, 2008, p.3). Systems may be defined as a set of independent but interlinked phenomena and identifying and using beneficial relationships and linkages between elements within a system is key to optimising the whole (Mingers and White, 2010). Meadows (1997) identified nine places of intervention to influence and change systems: (1) the mindset or paradigm out of which the system arises – the accepted status quo, influencing this can bring about the biggest changes, (2) the goals of the system –profit to survive and compete, but now incorporate social and environmental concerns, (3) the power of self-organisation – internal intervention akin to organisational or self-learning, (4) rules of the system –develop existing or new practices and policies beneficial to all stakeholders, (5) information flows – working towards transparency in the supply chain, (6) driving positive feedback loops – encourage desirable factors through promotion and aid for sustainable practices, (7) regulating negative feedback loops – control undesirable factors by legislating to minimize harmful materials or processes, eg REACH, (8) material stocks and flows – substituting with more sustainable material and (9) numbers -subsidies, taxes, standards.

Studies examining design and systems thinking have been few in comparison to areas such as management studies, operations management or town planning but some work that examined design process for (among others) automotive industry enabled a definition for whole system design approach to be posited (Charnley et al, 2011). "Whole system design is an integrated and emergent approach to the design of more radically innovative and sustainable solutions. It encourages those involved to look at a problem as a whole; take multiple factors into account and utilise relationships between different parts of the problem as opposed to addressing one aspect at a time" (Charnley et al, 2011, p. 172). Charnley et al's (2011) study identified eight overall themes they felt significantly influenced the process of whole system design: (1) forming and sustaining partnerships (as opposed to sub-contracting), (2) communication as often as possible and especially regarding system level discussions (details best kept away of team meetings for maximum efficiency), (3) trans-disciplinary approach – so that the design 'team' would have several perspectives of the design 'problem', (4) a shared sense of purpose – a team goal as well as the individual's own goals, (5) alignment of all parties' individual interests through honest discussion about requirements, needs, expectations and concerns of all, (6), use of and defining system boundaries to aid sense making about the process, (7) a facilitator who would not be the project leader or manager but rather a 'peace-maker' to help sustain dialogues throughout complex periods within the process and (8) integration of participants and disciplines to enable cross-disciplinary learning for design decisions to be developed appropriately.

1.2 Sustainability in the automotive industry

The European Union's End-of Life Vehicles (ELV) directive stipulates that, by 1st January 2015, 95% by weight of new end of life vehicles need to be reusable or be used for energy recovery end of life and 85% by weight needs to be recyclable (EURAPA, 2010) and that 'vehicle manufacturers and material and equipment manufacturers must: (a) endeavour to reduce the use of hazardous substances when designing vehicles, (b) design and produce vehicles which facilitate the dismantling, reuse, recovery and recycling of end-of-life vehicles, (c) increase the use of recycled materials in vehicle manufacture, (d) ensure that components of vehicles placed on the market after 1 July 2003 do not contain mercury, hexavalent chromium, cadmium or lead, except in the applications listed in Annex II of the Directive. (Normand, 2008). The Directive aims to prevent waste from the automotive sector by encouraging the vehicle manufacturers and their supply chain to make cars that are designed to aid dismantling, reuse and recycling (Vermeulen et al 2011).

The process of dealing with ELV's has been described elsewhere, but, in brief, the stages are as follows. An end of life vehicle is collected and brought to an Authorised Treatment Facility here it is deregistered and depolluted; car batteries, brake fluids, shock absorbers, heavy metals, petrol etc are removed to ensure that the car is safe to be dismantled. Dismantling is the process of taking a car apart so that valuable and reusable parts may be removed for manufacture or re-manufacture; as it labour intensive the amount of recovery is dependent on the economics of where this dismantling takes place (Santorini et al, 2010). The materials that cannot be readily dismantled, reused or recycled is then put into the shredding process where it is beaten into smaller pieces by hammer action (called automotive shredder residue) and then cyclonic treatment to separate residual metals left in the mixture. The mixture containing metals is termed as heavy ASR, that containing non-metallic (such glass, textiles, fibres, polyurethane foam) is known as lightweight ASR or car fluff (GHK and Bio Intelligence Service, 2006, Tian and Chen, 2014, Kanari, et al., 2003, Morselli et al, 2010).

ASR is classed as a hazardous material in the EU (Vermeulen et al, 2011) and it is the light weight ASR (car fluff) that is often sent to landfill or treated for energy recovery (eg through pyrolysis). As there is no standard definition of the term ASR therefore it is difficult to be precise regarding the data (Vermeleun at al 2011). The amount of ASR may be between 15-25% of the weight of a car and the amount of textiles and fibre materials may be anything between1%-45% of this light weight ASR (GHK and Bio Intelligence Services, 2006, Vermeulen et al, 2011).

Car seats are an important element in light weight ASR as they are the main source of polyurethane resin (PUR) and textiles, together contributing to 20% of the weight (Santorini et al 2010). The research conducted by Santorini et al (2010) noted that a typical car seat about 7% by weight of the car seat was textiles, while about 76% weight was due to the chassis, screws etc (the metallic areas) and that although they could recommend improvements to design for disassembly for attaching textile to the car seat frame, they felt that a complete redesign of headrests was necessary to enable dismantling/separation between textile, PUR and metal.

As the numbers of ELV is rising the need for separation and recyclability of the components becomes a greater need. Many vehicle manufacturers currently use design for disassembly processes using compatible chemicals, components and similar fibre types, to increase their recycling and reuse efficiencies. In the UK, the 85% measure was achieved in 2012 (Date, 2014) with 88.1% reuse and recovery rate. However, achieving the 95% target seems to be a challenging one (Gist, 2015). In the report, Gist explains that many EU countries have met the 95% target as the countries have developed zero landfill policies which have led to an increase in the incineration of the ASR; as more incineration sites are opened, there is a need for more feedstock, so prices at the gates are lowered thus more incineration… (Gist, 2015). Interestingly an ELV collector within the UK has stated that they have already met the 95% target however they have not explained how this has been achieved (Date, 2014). This collector (Cartakeback) runs a national collection system that is linked to many of the major car manufacturers, contracts many of the ATF's regionally to enable them to guarantee a free take-back service for consumers and depollution capacity of all possible arisings (BVSF. 2014).

1.3 Textiles within the automotive industry

The automotive industry is the single largest manufacturing activity in the world (Suthikarnnarunai, 2006) Automotive Supply Chain and Logistics Management. Retrieved from: http://www.iaeng.org/publication/IMECS2008/IMECS2008_pp1800-1806.pdf). The global market for vehicle interiors, estimated to rise to approximately US$210 billion by 2015 (Russell & Tipper, 2008; Shishoo, 2008, pp. 17-18) is expected to correspond with the increased use of textiles used within automotive; in a medium sized vehicle it is expected to rise from 21kg in 2008 to 35kg by 2020 (Normand, 2008 citing Saxony Textile Research Institute, 2005; Russell & Tipper, 2008). This is in part due to aesthetics as well as weight reduction. Key drivers in the automotive industry are aesthetics, comfort and safety of the end user alongside low weight (which reduces the amount of CO^2 emitted), lower energy consumption and the recycling of the vehicle at the end of life (Stegmaier et al., 2008, p. 43). Vehicles are becoming more adaptive to suit the desires of the 'individual' consumer, with more time allocated to being inside an automotive, differentiation is the key to mass appeal (Fung & Hardcastile, 2001; Powell, 2008). Nonetheless at present cost remains the key to successful production (Fung & Hardcastile, 2001, p. xi).

The automotive industry currently uses up to 15% of the world's steel production (Suthikarnnarunai, 2006) but this can be reduced by using textile composites and hardened steel in strategic load bearing areas but concerns about the availability of raw materials to harden steel has led to sourcing alternative processes that require less steel (Cullen et al, 2010). Examples include 3D woven fabrics using 'aluminium oxide infused with aluminium, giving strength and stiffness of steel with only a fraction of the weight' and offering many possibilities to reduce weight but maintain strength within the automotive industry (Excellence, 2011). Also carbon fibres with plastic composites to make car bodies also help reduce weight and achieving less fuel consumption as well as reduced use of steel.

There are various forms of automotive textiles ranging from consumer facing seat coverings, headliners, door and side-panel coverings, pillar coverings, sun-visors to those serving a technical function such as upholstery, seating, floor covering, trunk liners, airbags, thermal and sound insulation, filet fabrics battery separators, hose/belt products, tyres, textile-reinforced flexible and hard composites (Shishoo, 2008, p. xxi).

All textiles in the automotive industry need to pass specific tests in relation to mechanical, physical and chemical properties. Powell noted over 30 tests for textiles in automotive based on British (BS ISO), American (ASTM) and German (DIN) standards (Powell, 2008). As well as these standards some manufactures have their own specific standards to be met, these are called technical delivery conditions (TC) (Stegmaier, et al., 2008). The fibres used in automotive textiles for interiors is polyester and the use of recycled polyester is also feasible (whether from pre- or post-consumer consumption of plastic bottles)

Given the issues regarding achieving the 95% target through recycling rather than energy recovery from lightweight ASR, it could be argued that developing ways of retaining the values inherent in the textiles component (between 1%-45% by weight of the ASR) may contribute towards achieving the target through recycling. In the EU automotive industry, environmental sustainability of textiles is not (yet) the main focus of the car companies' sustainability efforts; which centre on fuel efficiency and lightweight cars. The life of a vehicle can be up to 15 years (Santorini et al 2010) and so vehicle manufacturers are hesitant to make environmental sustainable improvements regarding "peripheral" parts of the car which customers are less likely to ask about; and where the influence on sales and reputation is perceived as uncertain. On the other hand, seating textiles are visible to the customer; and so it is important to understand the internal and external pressures which the design team faces. Therefore, the design process is analysed to get a detailed understanding of the factors driving the design decisions.

2. Research methodology

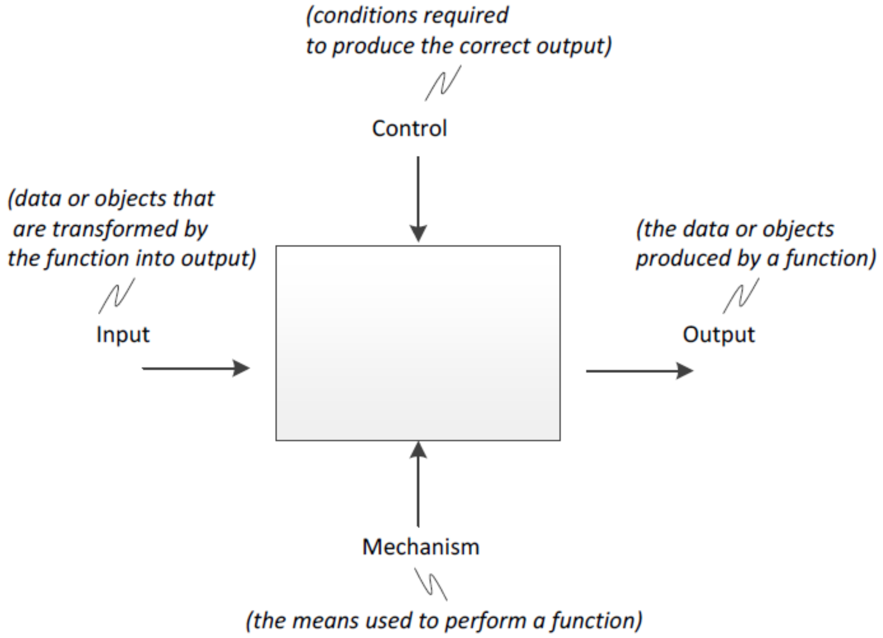
A single case study, according to Yin (2009), was conducted using a number of semi-structured interviews from November 2011 until July 2014, (on site and off site) with the managing director, design & development director, designers and members of the logistics and technical team. The interviews were recorded, transcribed and triangulated with the company's documents and literature regarding product development process. The analysis was validated by the design and development director. The commercial sensitivity, the detailed nature of the analysis and associated time requirements necessitated a single case study. Sage AI (UK) were chosen as a case study company due to their strong interest in environmental product development; and existing close working relationships with the University.

To analyse the design process, we used IDEF modelling, a standardized and widely used method to model manufacturing processes (Rashid & Ismail, 2007). Used as a visual tool, it helps describe, analyse and communicate ideas (Yu & Wright, 1997). It has proven effective for detailed system analysis (Knowledge Based Systems, 2010). The modelling often starts from a description of the process at the highest level; which is then broken down hierarchically to the level of detail required for a meaningful analysis. This allows the user to describe the details of complex processes while keeping a good overview of the activities (Sugiyama et al., 2008).

According to the IDEF-0 standard the purpose and viewpoint, system boundaries and meaning of the arrows should be defined. For this study, the purpose of the model was to understand the design development process of the case study company and to identify where environmentally relevant decisions are made in this process. The model takes the perspective of the design and development director, with the intention to focus on the steps in the design and product development process stages. As a consequence, the model includes all processes which the design team are directly involved in, starting with research and development, design concept development and selection by client, up to the point where a Master sample of the fabric has been selected as a template for production.

Fig. 1 demonstrates a basic structure of the IDEF-0 (National Institute of Standards and Technology, 1993, Kikuchi et al., 2012). The control arrows in the IDEF-0 model represent factors which need to be taken into account in the respective process step. They are the most relevant factors for the identification of the barriers.

Figure 1: Basic structure of IDEF-0, based on (National Institute of Standards and Technology, 1993)



The purpose of the IDEF-0 modelling was to obtain a detailed examination of the product design/ development process at the case study company and was used as a basis to identify the following:

1) where in the design process the most environmentally relevant decisions are being made
2) the crucial factors affecting these decisions, and
3) barriers to and enablers for environmental product development in the current design process; using the introduction of recycled yarn as a particular case study example.

3. Results and discussion

3.1 Sage AI (UK) Company background

Originally a part of Milliken Automotive and the Viktor Achter Groups. Sage Automotive Interiors (Sage AI) business is headquartered in the US, and solely in the automotive sector with bases in Poland, Japan, India, South America, China. The Sage AI business is entirely related to design of textiles, incorporating engineered and technical qualities to add value for the automotive industry. Sustainability and innovation is paramount to their vision.

Sage AI produces textiles interiors based on two manufacturing routes: woven or knitted. Most developments are related to enhancing these processes, e.g. through embossing, stitch and HF welding. The samples are developed through their plants overseas thus knowledge of their capabilities is essential (accrued through regular monthly visits and relationship building through creative or technical designers to partner manufactures). Most innovations are for enhancing the fabrics, e.g. rotary embossing, twelve head embroidery machine and HF welding. As many vehicle manufacturers produce shorter runs and offer special editions to add more interest to the colour and design of the automotive, Sage use embroidery to deliver mass customisation service. When developing initial ideas (for either internal or external clients) Sage AI liaise with their suppliers' technicians to establish feasibility with partner companies; where, if it is not possible, they will develop new supplier relationships and run feasibility trials.

Sage AI (UK) own manufacturing plants in Poland (weave) and Egypt (knit). The creative or technical designers visit the manufacturers monthly to maintain communication and address any design/production issues. Costs limit fibre choice usually to polyester which is then designed for variety of looks: e.g. highly lustrous, soft matt, textured and novelty yarns to create interest in the woven and knitted fabrics. Wool can be used but is expensive therefore limited (Sage used wool for the BMWi3). Yarns are supplied by Autofil Worldwide Ltd, who also piece- or yarn-dye and texturize to a very wide variety of looks and feel; the blend, has to be visually appealing to the customer (the OEM), pass various rigorous tests (such as abrasion and light fastness) be durable (up to 10 years) and most importantly - cost effective.

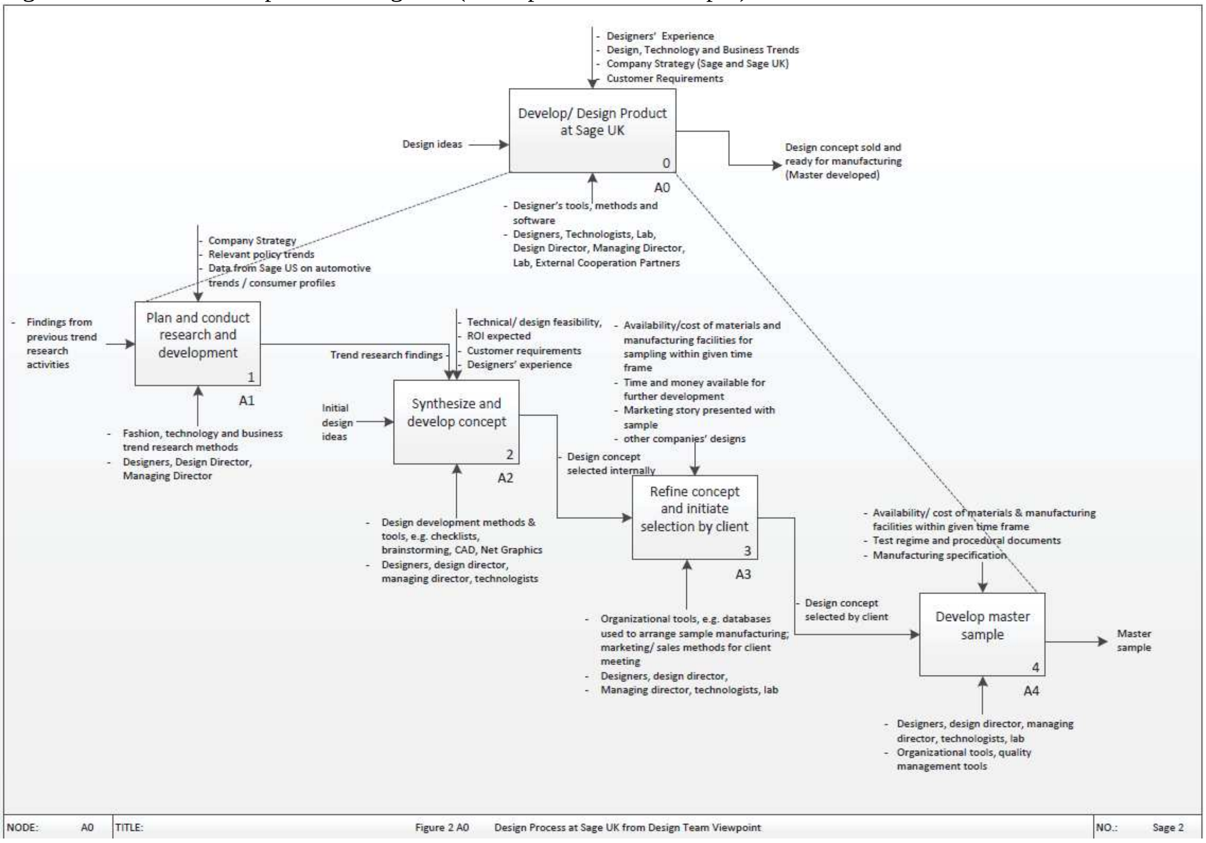
3.2 Application of textiles to seating

The manufactured polyester fabrics are usually laminated with foam and a lightweight fabric ‘scrim’. These are manufactured to a schedule and then shipped to a cut and sew company. These companies, often part of the final seat manufacturer, receive the fabric in roll form and mechanically cut parts which are then sewn together to create a seat cover. The covers are then usually shipped, often over long distances, to where the seat itself is being made, where they are incorporated into the final seat. The seat is then sequenced in trackside as the car they are destined for is being made Just-in-Time; the seat assembler receives notification of which type colour, style manufacture of the seat is required a few hours before it is required to meet the rest of the car on the assembly line. Other parts e.g., engines, headliners, instrument panels, doors etc., are equally sequenced in.

3.3 The design and product development process

The product development process may take between 3-5 years from brief setting to final vehicle production. This is extended by the additional seven years approximate length of time that the textiles will be in vehicle. Figure 2 outlines the process from concept to master sample; for ease of describing the process, stages have been assigned various developmental stages of the process (stages A1-A4).

Figure 2: Product development at Sage AI (concept to Master sample)



Product development or innovation begins with a brief, either from the customer/client (OEM, which designers interviewed termed as “*client based”*) or in-house through their own product/consumer knowledge (e.g. designer, manager, etc – the designers at interviewed termed this as ‘open-*line’ brief*). Sage AI developed FXC for Honda from a brief set by Honda, whereas YES Essentials was developed through an open-line brief based on internal knowledge and consumer research. It is not uncommon for the OEM’s to tenders briefs to more than one supplier at a time. OEM’s distribute requirements via a brief to specify requirements in terms of objectives for the textiles, this process may commence up to three to five years in advance of the final vehicle production dependent on whether incremental or innovative design is involved. Dependent on the client’s requirements the brief may focus on pattern requirements, technological developments, whilst others may be more responsive to emotive desires of the consumer.

Figure 3a Open line brief product development

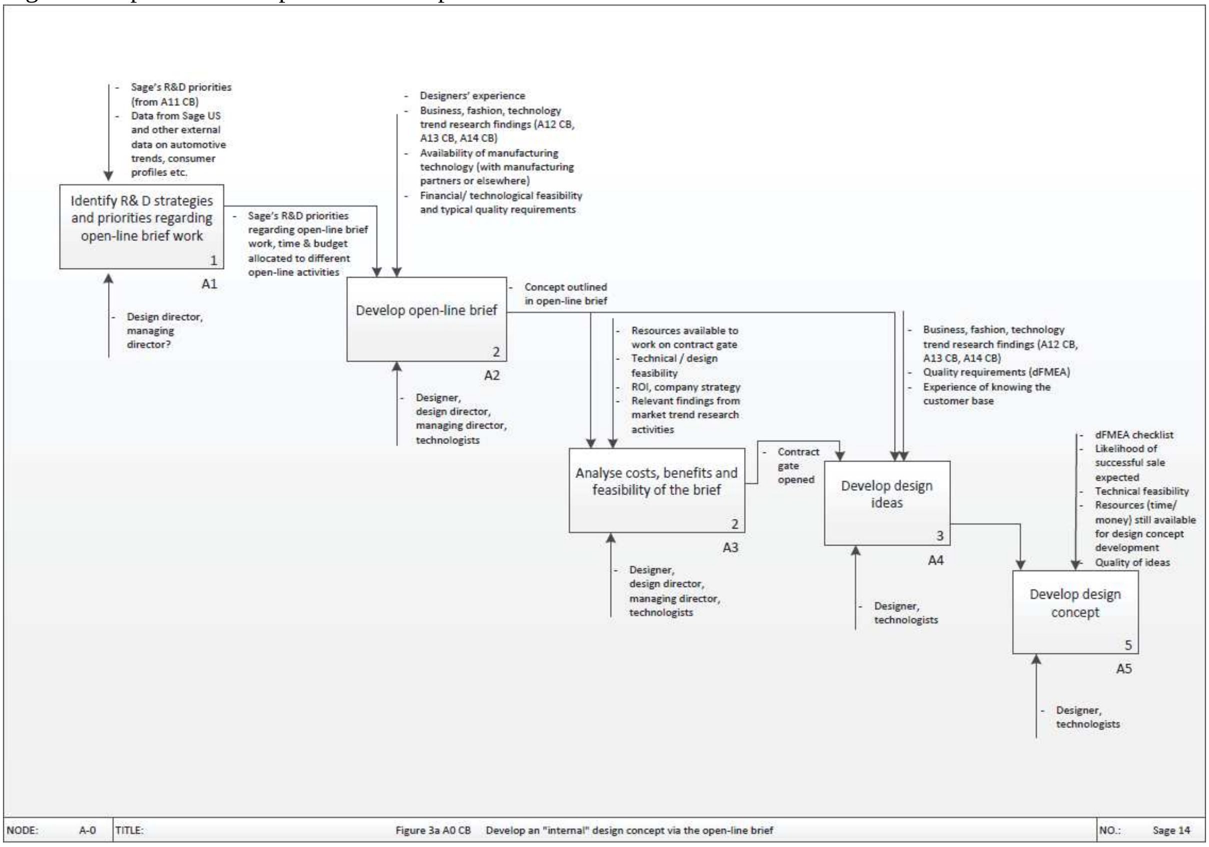
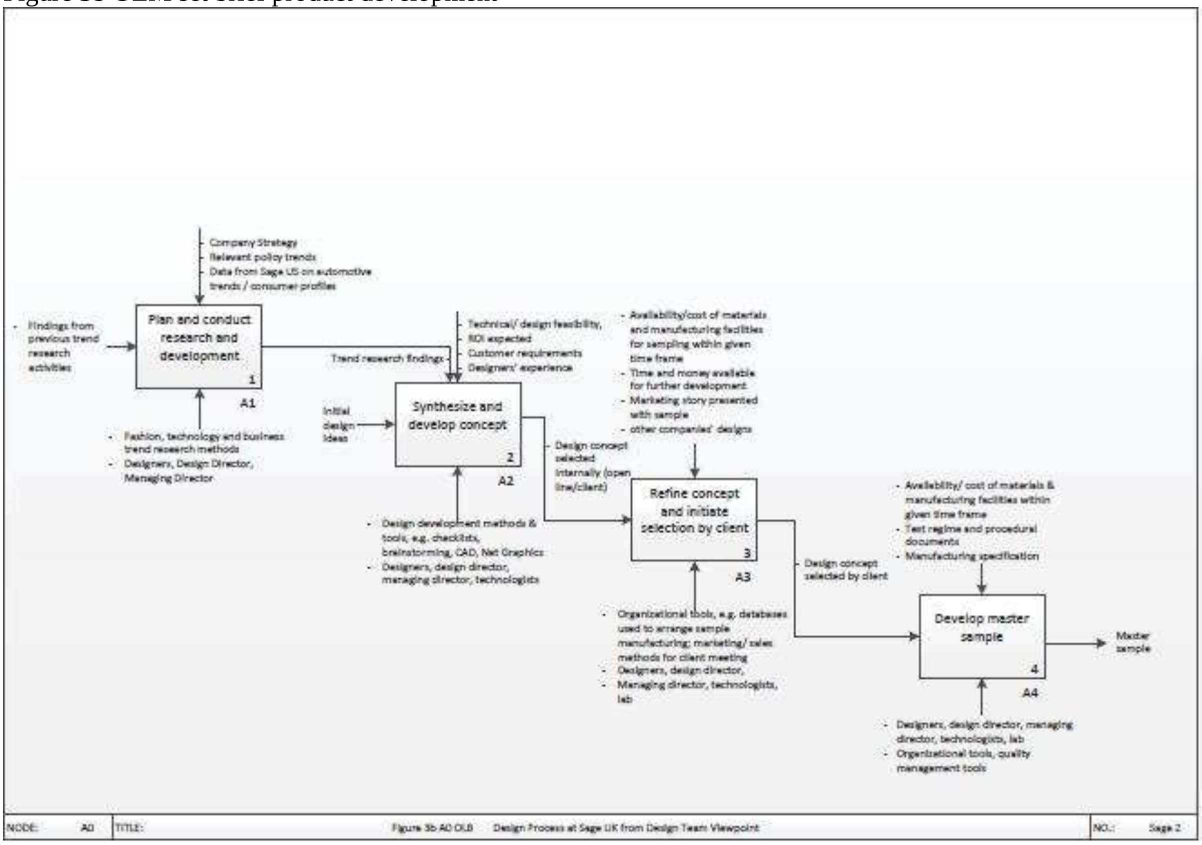


Figure 3b OEM set brief product development



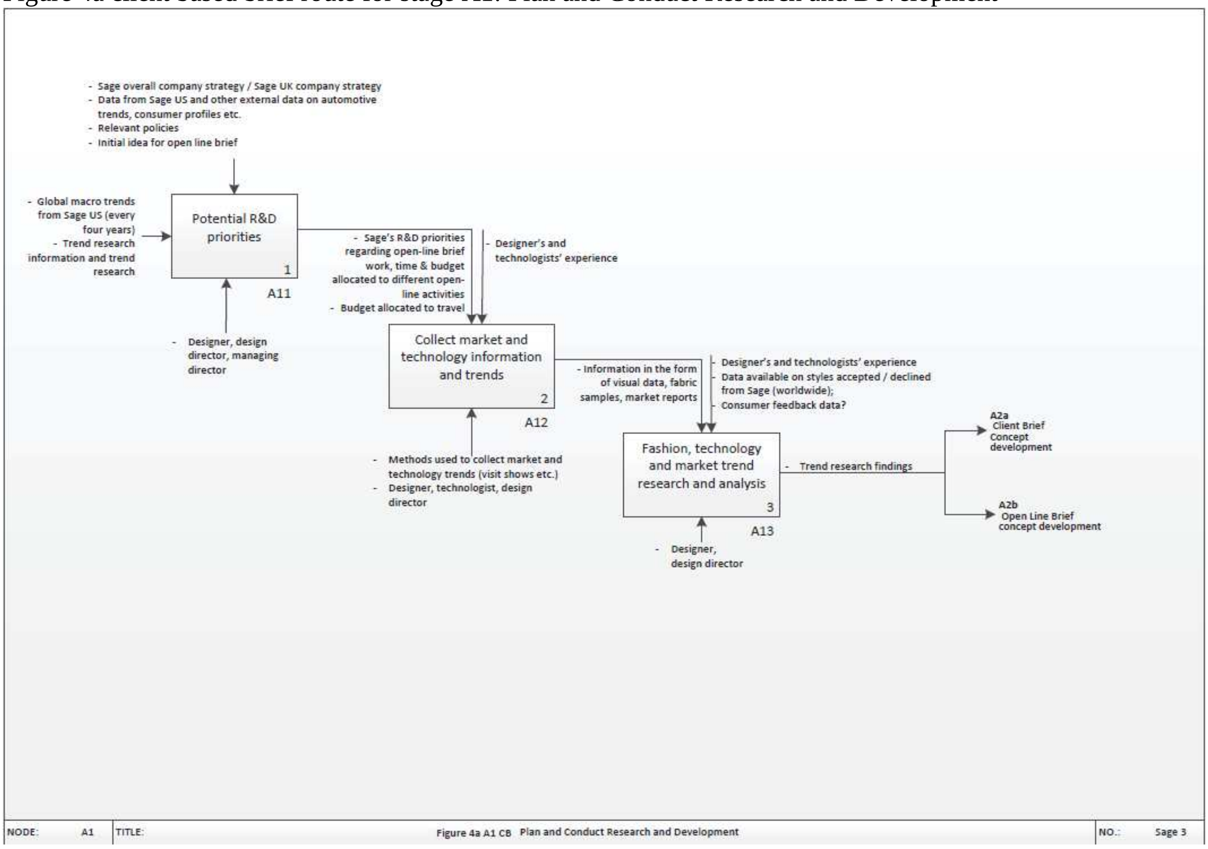
It may be noted that an extra consideration needs to take place when developing a concept by open-line brief, in that the technical feasibilities and standards for the concept need to be researched, moreover, internal briefs are no longer common at Sage as the resources implications and risks to approval by a potential client are high and raise too many complex questions when considering how copyright is assigned and to whom (Sage or their client).

Stage A1: Plan and Conduct Research and Development
This initial stage A1 can take between two weeks and two months dependent on the client's needs. According to Powell a brief will consist of performance [standards] and cost parameters, colour, pattern, scale of pattern, lustre and handle which is then taken forwards by the designers (Powell, 2008a). Timing and major stage-gates will also be confirmed. If the initial stage-gate is short the design team will show concepts already in situ to support quick turnaround of sampling; when the stage-gate is long the designers will develop new concepts for a particular brief, this may include two stages prior to sampling.

Vehicle interiors are mainly plain, striped, checked or small scale ditsies in neutral colouring with the addition of a small percentage of a brighter accent colour to add interest (Powell, 2008a). Various OEMs who produce shorter runs have started to offer special editions to add more interest into the colour and design of the automotive (Powell, 2008b citing Powell 2006). As already stated vehicles are developed up to five years in advance, alongside this is the timeframe of seven years that the textiles will be in vehicle production before an updated model is developed and ultimately replaces it. Thus the fabric has to remain on trend for a much lengthier amount of time than fashion or home interiors in terms of appearance and colour.

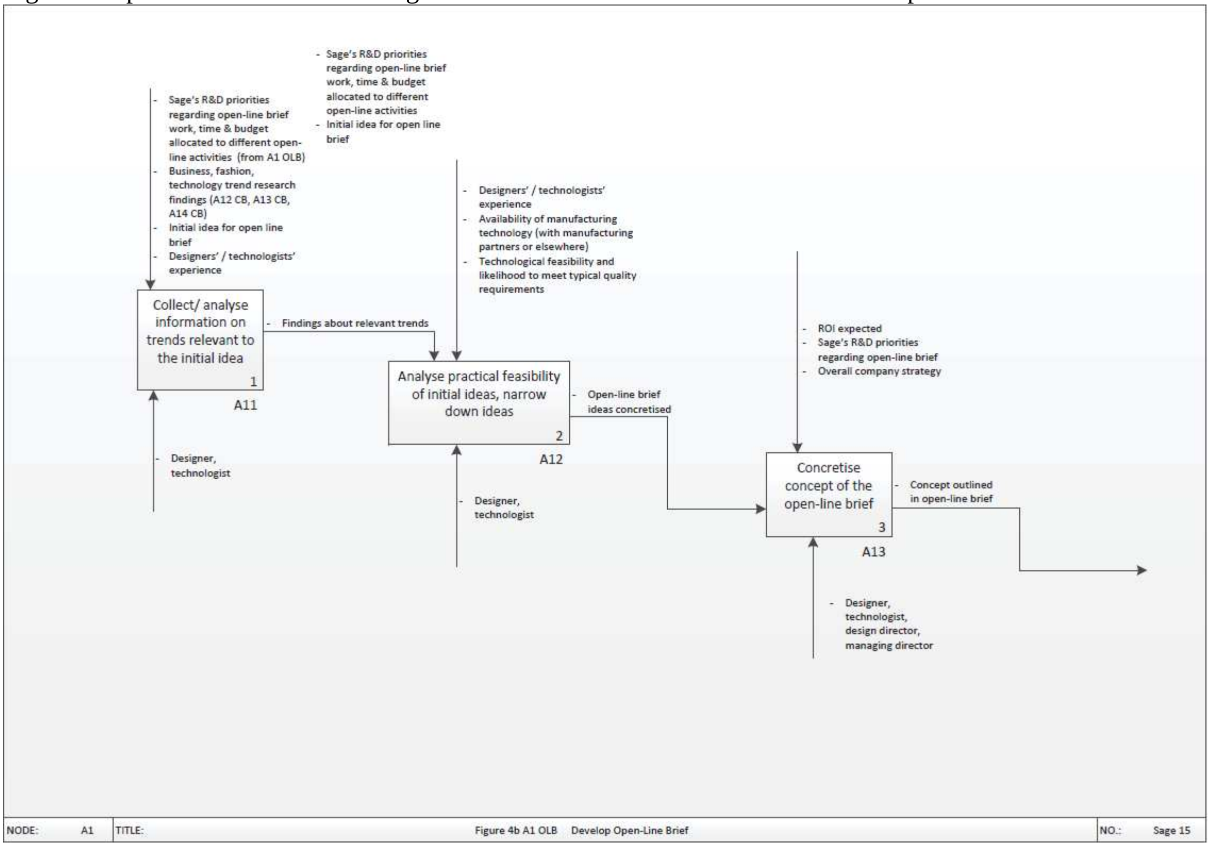
Due to the long lead times a global macro-trends study is projected every four years and micro-trends analysed such as "luxury", "sports", "comfort" to focus the design team. Sage AI used to profiles geographically but now reference according to age and lifestyle, e.g., "youth" and "active". Other elements to be considered are environmental trends, colour, texture and consumer profile. The designers produce a global colour show consisting of four themes to maintain constant fabric design and development and visit trade shows to keep abreast of latest yarn or fabric development techniques and suppliers. Figure 4a illustrates the open-line brief route while 4b illustrates the OEM set route

Figure 4a client based brief route for stage A1: Plan and Conduct Research and Development



The development of an internal briefs provides an opportunity for SAGE to develop environmentally friendly innovations. Whether those are taken up by the car manufacturers depends on trends and politics, company strategies and product cost. The risks of the product being accepted are high at this stage; therefore, it is important for Sage to research trends, politics, potential clients' company strategies and estimate the product's cost and feasibility, all of this is resource intensive.

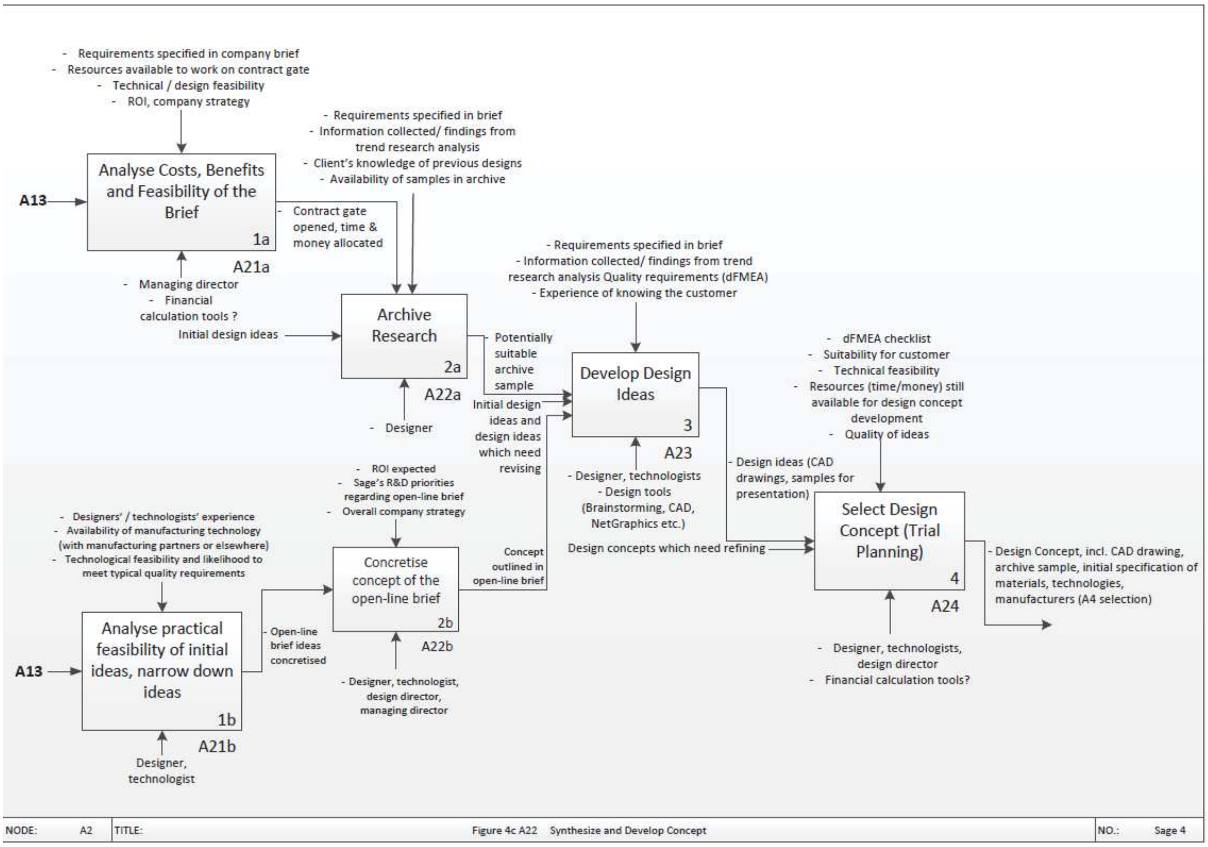
Figure 4b open-line brief route for stage A1: Plan and Conduct Research and Development



Stage A2: synthesis and development of concept

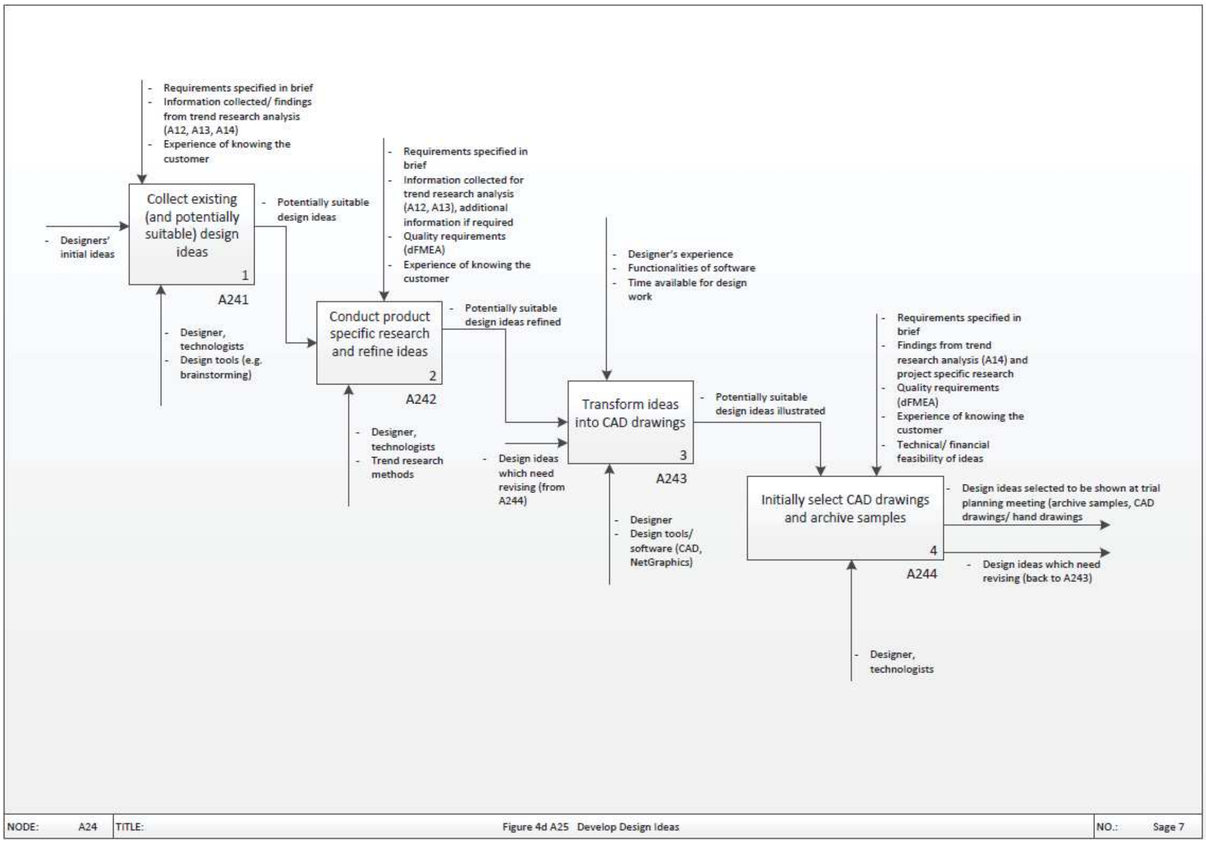
The initial idea is transferred into a CAD software. Figure 4c illustrates that the open-line brief route requires an examination of the return on investment of resources spent on developing the concept and its fit with the company's strategic priorities before they proceed to developing it into design ideas for the client.

Figure 4c stage A2: synthesis and development of concept



During stage A2, the design idea is developed into a concept (that will be discussed at a meeting with potential clients). At stage A24, the design idea is examined for selection with regards to whether to continue to refine or not. The design ideas might not be good enough (in which case, they need to go back one step). A dFMEA (design Functional Modes and Effects Analysis) review is undertaken which outlines the technical requirements (included in dFMEA) to narrow down the selection of potential fabrics, material; much of this depends on the design team's knowledge of what is likely to work. Technological requirements are manufacturer dependent. Figure 4d illustrates the activities surrounding the decision to select the design concept to develop further.

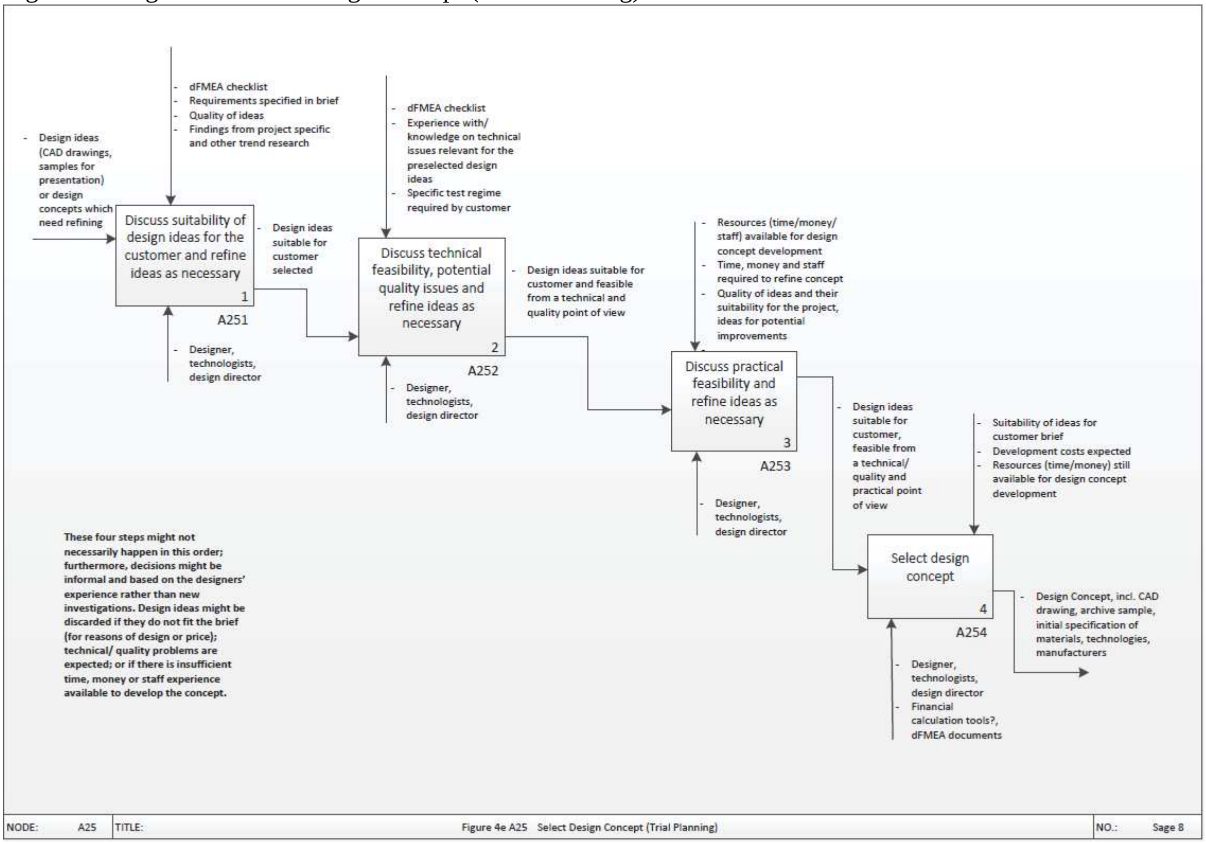
Figure 4d: stage A24: developing the design idea



At stage A25, the concept is refined towards developing a sample. The design concept (perhaps. in the form of a CAD illustration, or a selection of archive samples), includes specification of materials, technologies required for the making, sources of laminators, etc.

Figure 4e illustrates the activities involved in refining the idea into a concept that will be developed for discussion in a client meeting. The concept is produced on a CAD programme (in this case NED Graphics), this is emailed to the specified manufacturing location and processors and (dependent on colourways) will take four to six weeks for sampling to materialise. If the colour of the yarn is already available (e.g. black) this would be a four week process; however if the yarn needs to be dyed specifically to match other elements of the interior such as vinyls and leathers this can take approximately six weeks.

Figure 4e Stage A25: select design concept (Trial Planning)



Stage A3: Refine concept and initiate selection by client

Concepts considered feasible for client discussions are developed into a sample representative of the actual fabric that may be used by the client company (figure 5a).

Samples to be considered may be new samples designed or they may be archival samples or samples that did not quite achieve the appropriate standards in a previous round of testing. The overriding considerations are return on investment (likelihood to get the job, likelihood to get good money out of job if accepted), availability of machinery and raw material within specified time frame, time availability and cost of sampling. The initial decision making regarding whether a sample should be put into manufacture is illustrated in figure 5b.

Figure 5a Stage A3: Refine concept and initiate selection by client

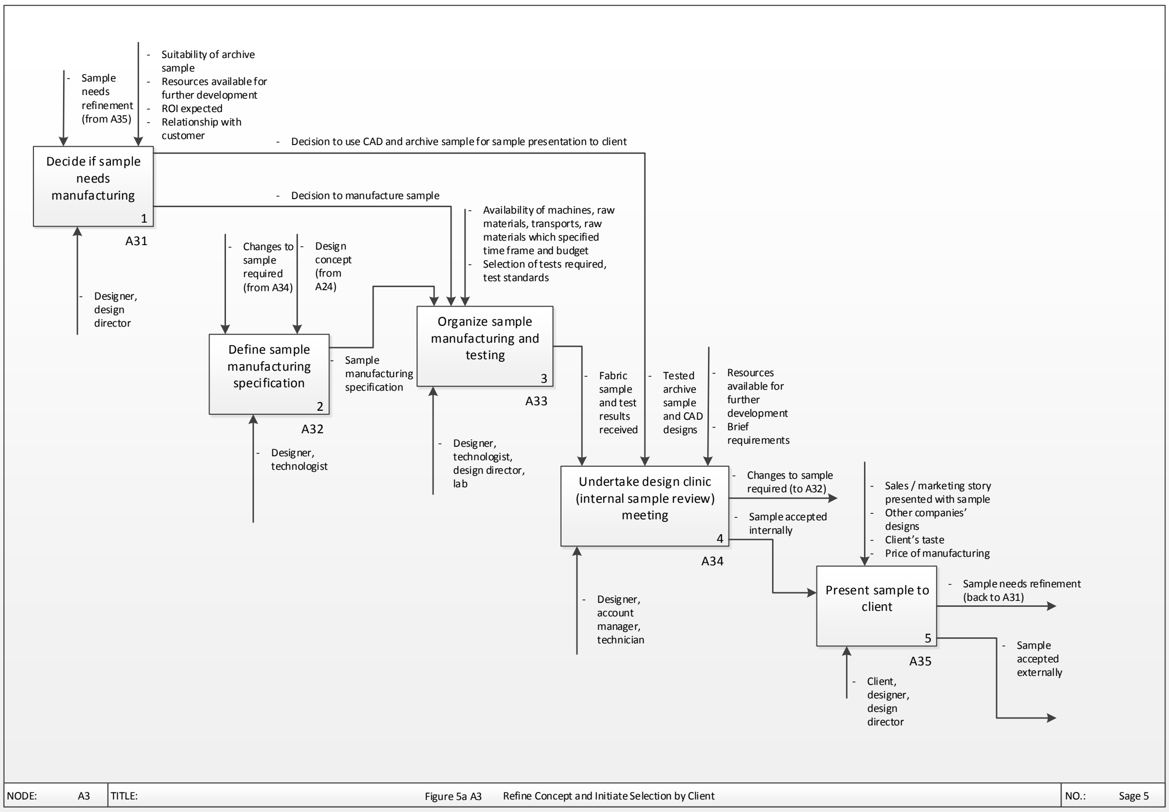
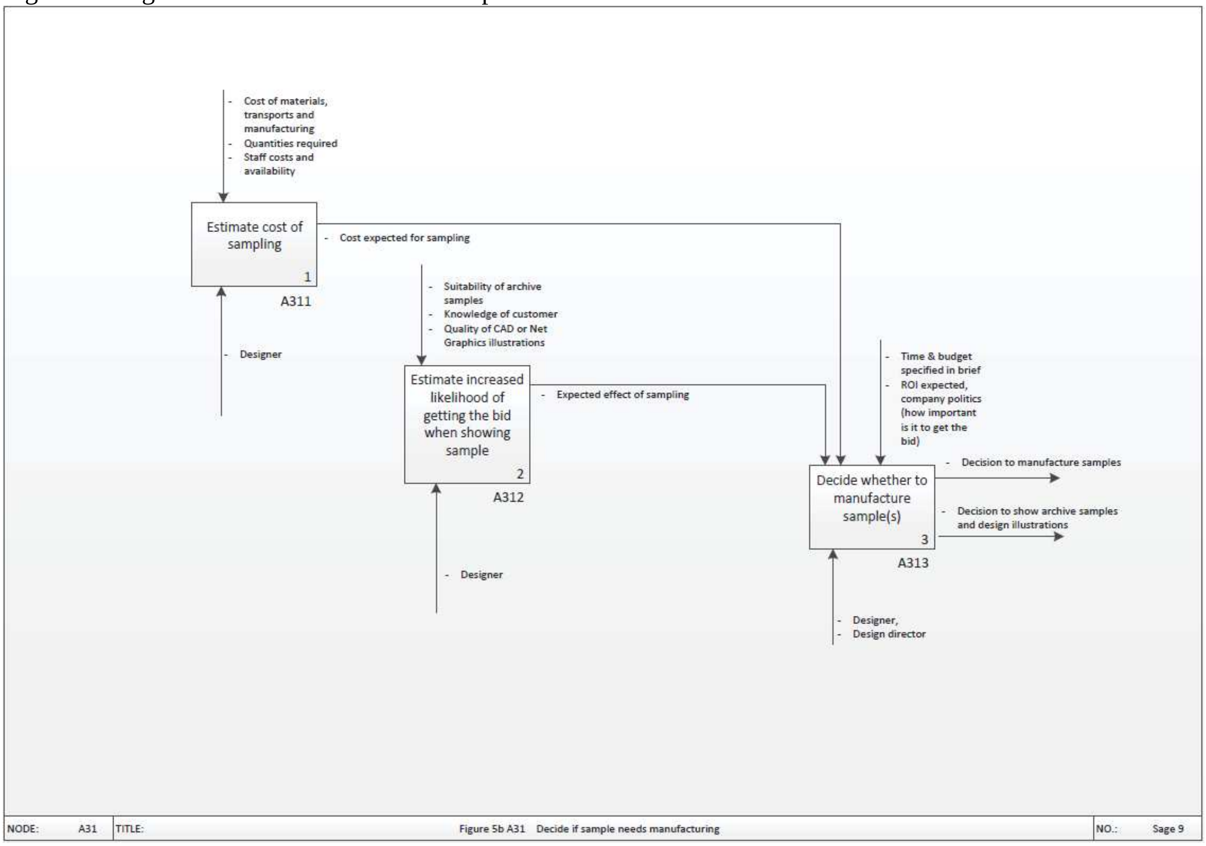
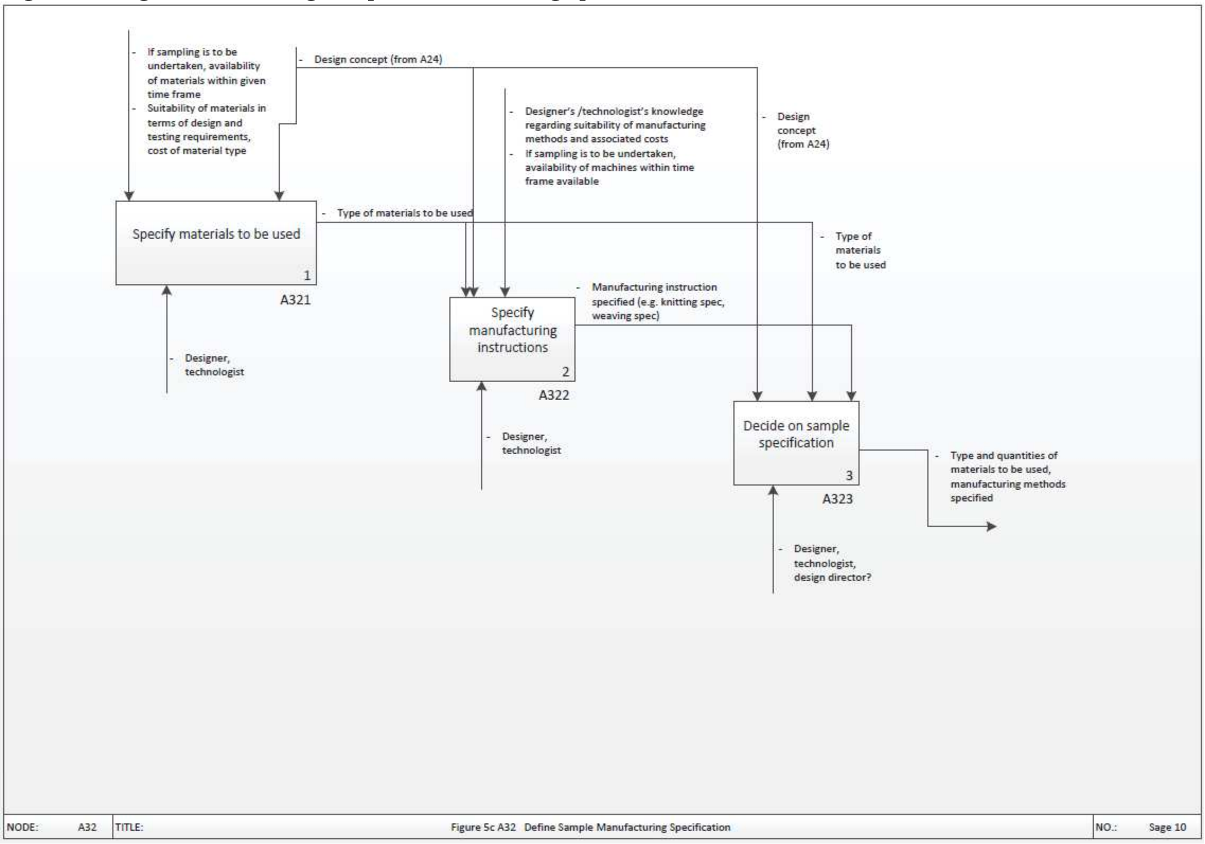


Figure 5b stage A31: initial decision if a sample should be manufactured



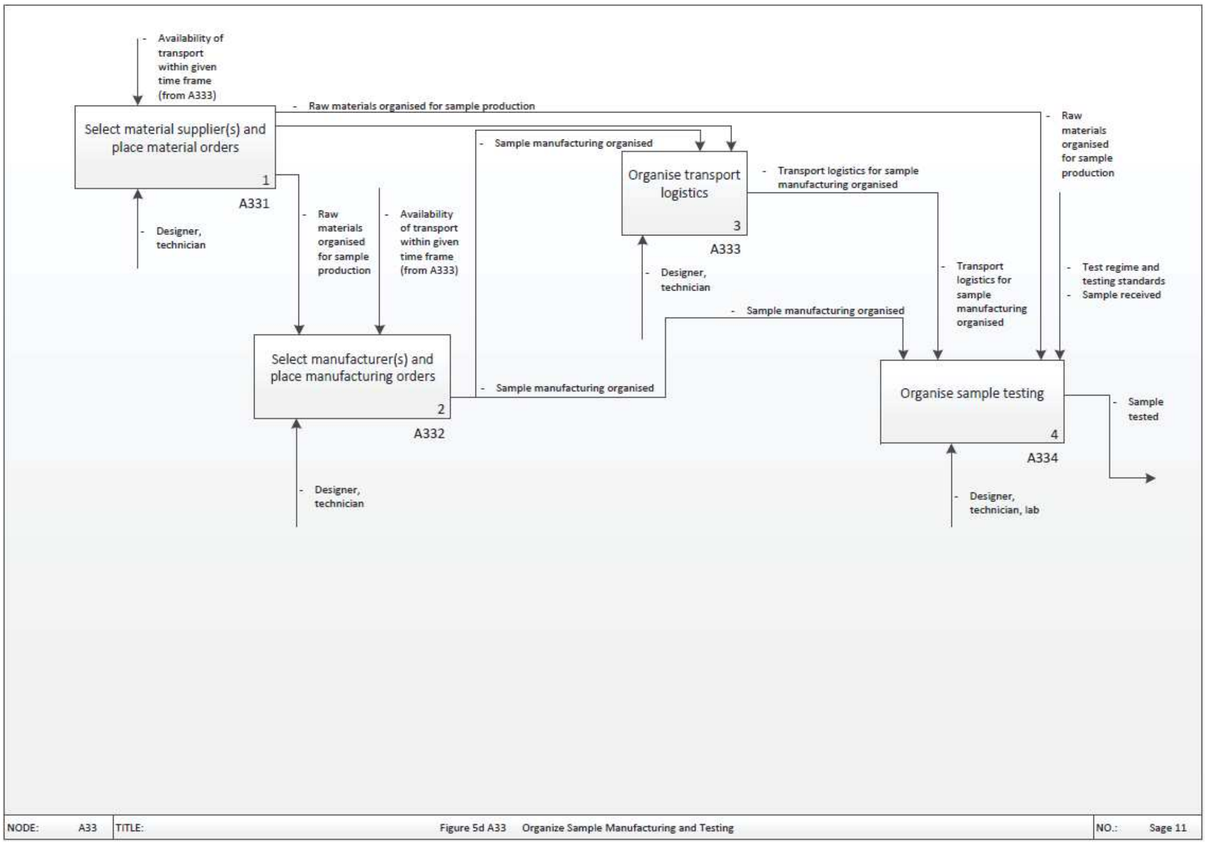
Once the decision is made to take a concept to the manufacturing level, specifications for manufacturing need to be developed and defined, as illustrated in figure 5c.

Figure 5c stage A32: defining sample manufacturing specification



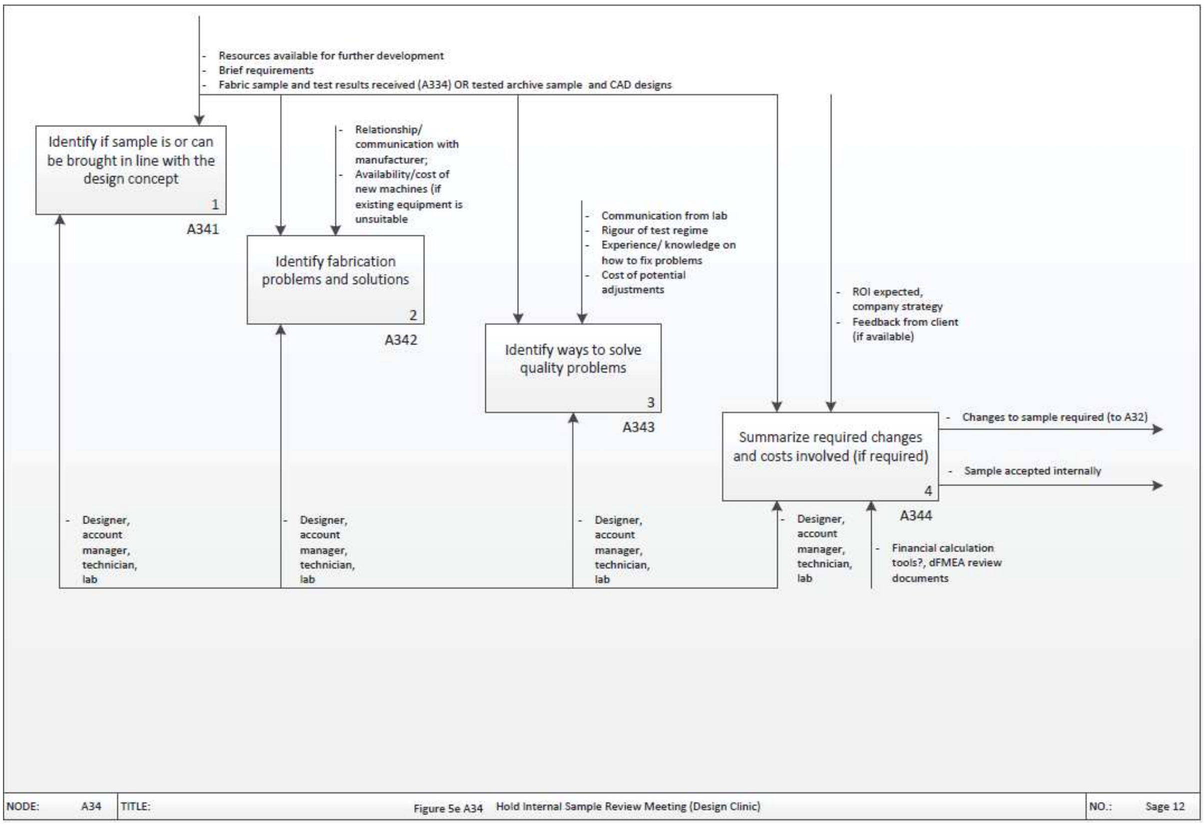
As the sample specifications are being defined, there is also the need to organise the logistics for the transportation of the samples and their testing. Samples in automotive textiles are many metres of fabrics, representing bulk and hence the requirement for cost and time efficiencies to be met, as illustrated in figure 5d.

Figure 5d stage A33: organising sample manufacturing and testing



Once tested, the sample is then examined by the design team for quality of manufacture, standard of testing and financial implications. Any problems are identified with appropriate rectification routes. Samples accepted through this internal design review are presented to the client company (stage A35) who will make the decision to either review the sample again after specified modifications or to agree that the sample is further developed for manufacture.

Figure 5e A34: Hold an Internal Review Meeting (Design Clinic)



Stage A4: develop master sample

Once the clients have reviewed the samples, decisions are made regarding the merits of developing the sample for production, the first stage of this is the ‘master sample’. Approved samples from the client review at stage A35 undergo a second set of testing and colour-tuning (figure 6), if not approved design alterations and further sampling will occur. When samples and testing are approved the design process is finalised, a term described by Sage AI as ‘mastering’ this is whereby the whole product is fixed (yarns, design, etc), contracts are raised, the client firm is financially committed and the design is then assigned to production.

Figure 6 Stage A4: developing the Master Sample

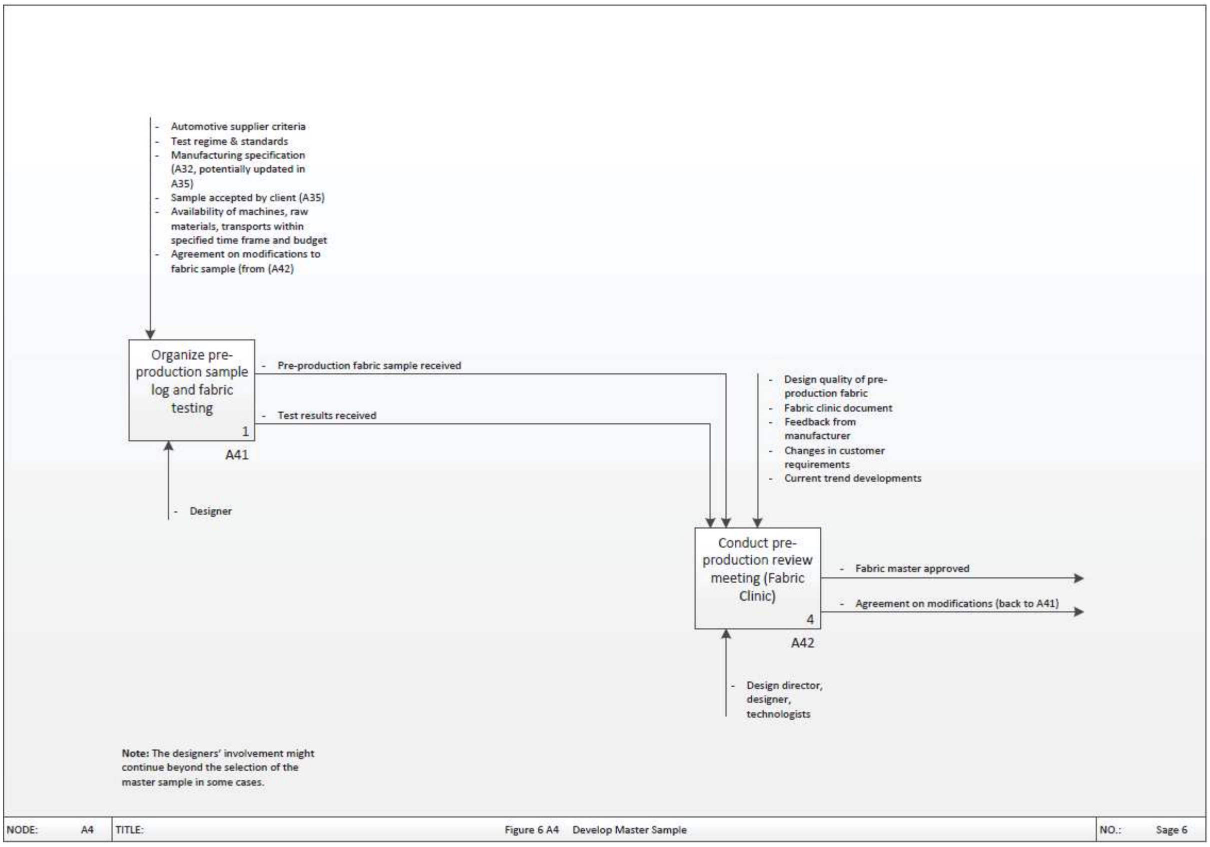


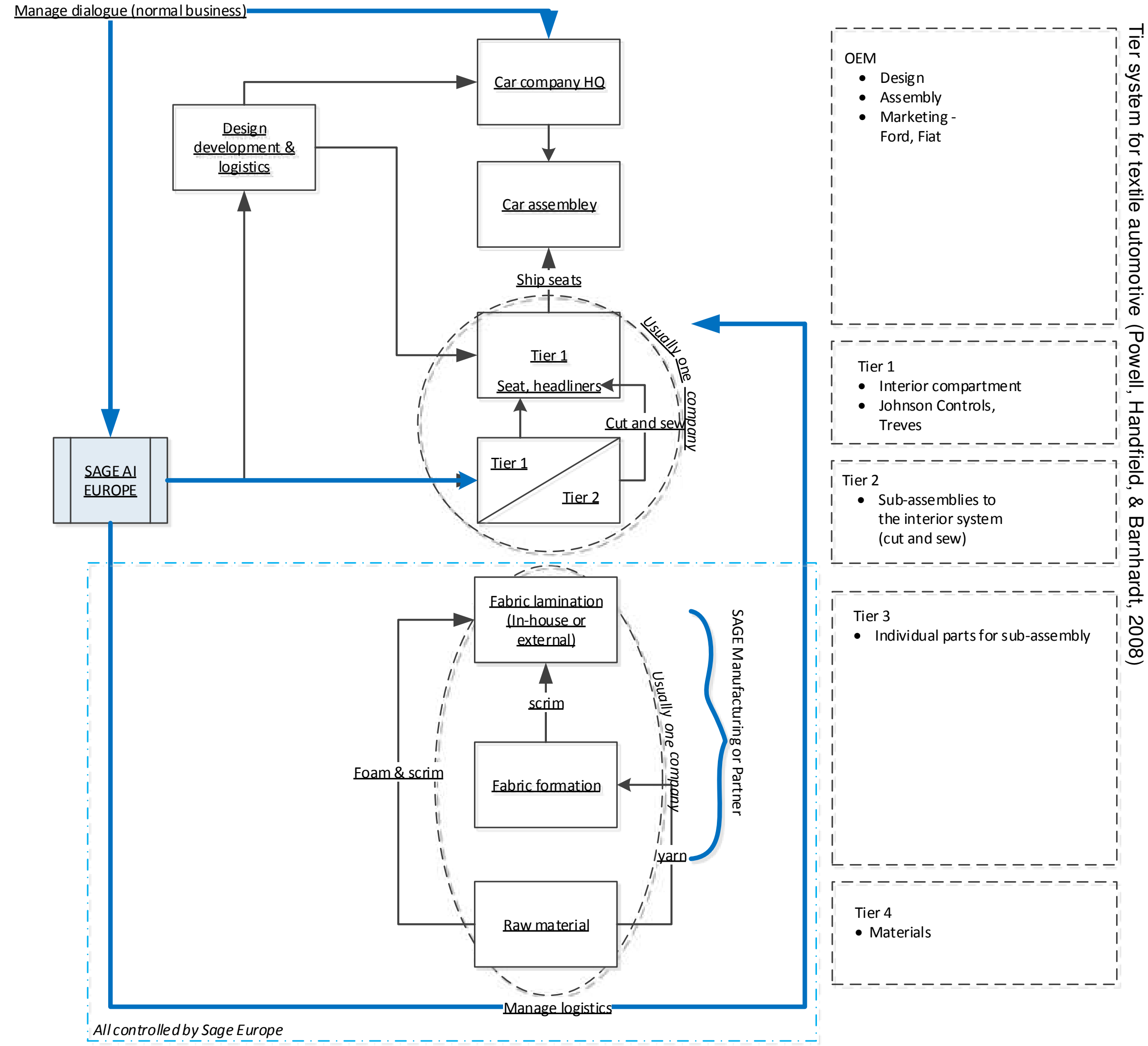
Figure 6 A4 Develop Master Sample

4. Discussion

4.1 The automotive assembly system

Often described as tiered: up to four tiers excluding the car manufacturers – the original equipment manufacturers (OEMs). Tier one supplies interior compartments, eg seats, engines, floors; tier two carry out sub assembly activities such as cut and sew and supply parts such as headliners. Tier three supply the manufacturing for the upholstery whilst tier four supply the materials (Shishoo, R., 2008). Tiers 1 and 2 companies may be integrated and 'cut and sew' operations may be carried out by the same company. Fabric laminators supply to site of cut and sew operations (Tier 2). The fabric formation companies may conduct fabric lamination in-house, or out-source. There are many permutations; companies may supply yarn direct to the fabric formation company, foam and scrim direct to a fabric lamination company or only yarn to the fabric formation company and the fabric formation company supplies the scrim to the fabric lamination company. Moreover, the three companies may be integrated (Taylor, 2012). An example is the consolidation by Tier 1 companies. The OEM's, frustrated by the increasingly longer lead times and operational constraints, only worked with fabric suppliers with cut and sew operations. Tier 1 companies (eg Johnson Controls) have bought out fabric companies and become vertically integrated companies with control of upstream and downstream activities making the full range of products from seats, instrument panels, headliners etc. With 25% of the market, Johnson Controls vertical integration captures increasing amount of value along the chain but loses flexibility and speed. The independent status of Sage AI, is advantageous because it affords flexibility and speed within the system (Taylor, 2012).Sage AI has maintained sustainability as core to their corporate values from Milliken and normally use polyester yarns for their textile products that are visible within the automotive (because it is cost effective, recyclable and meets the rigorous test requirements). The polyester may be coloured and texturised to a very wide variety of looks and feel that are cost effective, visually appealing to the customer (the OEM), and pass a number of rigorous tests (such as abrasion and light fastness) so that it will last for up to 10 years.

Figure 7: Sage AI (UK) place in the automotive chain



4.2 Design decisions regarding using recycled polyester

Consolidation of suppliers means that automotive textiles interiors yarns are sourced from a small pool of yarn suppliers, with the resulting impact on cost. Cost of using recycled yarns appears to be in the processing of the yarn: there is a surcharge/premium in terms of the raw materials which is based on the polyester and not the plastics making it difficult for the OEM customer to understand the costing. The cost implications are, for example, 7% mark up on fabric that is 40% recycled and 11% on fabric that is 100% recycled; when this is taken back to the yarn, the cost is double or three times that on the normal price of the yarns. According to Ford's research shared with Sage AI, the premiums charged on recycled yarns varies across the world: 10-15% (USA), 15-20% (China, India, Brazil), 20-25% (Europe), 20-30% (Korea) and 50-100% (Thailand).

As costs appear to be an overriding consideration, we examined the design process to identify where and how decisions were made that were directly related to considerations about using recycled yarns (and by implication the lamination process used). This is presented in table 1.

From table 1, it can be seen that there are few, if any, decisions that are under Sage AI's control, save the decision to develop an open-line brief. This is a route that is not now very common for Sage AI as it is risk-laden and demands resources in terms of time and money with no guarantees of developing a sample that wins a contract. However, having developed fabric samples in this way to show at various industry shows did place them as companies who are not only interested in sustainability but actively seeking solutions.

Decisions around developing sustainable textiles solutions for automotives are through negotiation with the lead firm, the OEM that is seeking to manufacture the model.

Table 1: decision making for using recycled yarn

Decision	Decision explained	Relevance for environmental sustainability	Relevance in recycled yarn scenario?
Determination of R&D priorities (A11)	R&D priorities (including the level of detail at which this is defined), time & budget allocated to different open-line activities	level of priority given to EPD in R&D has direct implications for both innovative and incremental EPD activities (incl. level of detail about specific EPD aspects)	N/A
Decision whether to work on a company brief or not (contract gate opening) (A21a)	Decision whether to open a contract gate is made; a certain amount of time and money is allocated to the project	a) the decision whether to work on a brief which requires research into EPD is made, and the time and money allocated to the brief is determined (impacts on the likelihood of the bid being successful) b) the amount of time/ money allocated to a "conventional bid" affects the time left for work on specific EPD projects c) for any bid, the availability of resources (amount of time / number of staff members allocated to working on the bid) could influence whether there is scope for exploring EPD as part of the design development	Yes
Decision on which open-line briefs to take forward (internal product development work) (A21b & A21b)	The decision which open-line brief ideas to work on is taken/ open-line brief ideas are concretized	Taking the R&D priorities into account, the process of narrowing down design ideas requires a decision on whether to work on EPD as part of the R&D work - and what priority they are given over other R&D ideas - this may be an implicit or explicit process	N/A
Design idea development – decision which ideas to present (A23)	Design ideas are selected (CAD drawings, samples for presentation)	A decision whether to include design ideas which require sustainable materials and production methods is made.	Yes (combined analysis with design concept selection)
Design concept selection (A24)	Design Concept selected, incl. CAD drawing, archive sample, initial specification of materials, technologies, manufacturers (A4 selection)	The design concept selection will largely determine what the actual product will look like and how it will be made, which has direct implications for the environmental impact of its production.	Yes (combined analysis with design idea development)
Organization of sample manufacturing and testing (A33)	a) Suppliers and manufacturing partners are selected for the product sample (if successful, they are likely to be commissioned with the production of the product once it goes into production as well). b) testing is organized (test regime specified by the respective OEM)	The choice of suppliers and manufacturing partners will affect the environmental impact of the product. The importance of the choice of the manufacturing partners depends on the availability of alternatives and the variability between the manufacturing processes with regards to their environmental impact (e.g. the age of the machines used, materials used, energy sources etc.) - the differences are likely to be greater if the market is global.	Yes

4.3 The design process at Sage and systems thinking

The design process at Sage exhibits systems thinking to a degree. When compared to the study by Charnley et al (2011), it can be noted that Sage AI (UK) operate as far as possible interact with the car seat manufacturers and client OEMs as partners rather than sub-contractors. Developing closer links with the supplier of recycled polyester may help in identifying opportunities to develop recycled polyester textiles. With regards to communication, Sage AI (UK) have a vast range of mechanisms to do so. Not only do Sage AI keep the clients informed about the process but also they undertake a range of company performance measures and feed this back to themselves (eg time taken to deliver). Teamworking during the design process is multi-disciplinary and there is integration of the disciplines to enable learning across disciplines – the designers, technical and supply chain staff all come together and there is a very fuzzy boundary between designers and technical staff. Where systems thinking in the design process could be improved is in alignment of all parties' interests – requirements, needs and concerns. Here Sage AI (UK) was keen to promote their sustainability credentials having achieved Certificates for environmental management systems such as ISO 14001 and ISO 14001 or QS-9000 [an automotive standard developed by General Motors, Chrysler and Ford based on ISO 9000]. As products are developed in accordance to specifications set by the OEM in the brief, measurable sustainable criteria should help to evaluate the environmental credentials of the product. However, the overriding concern for the OEM is cost and as the case study with Sage AI (UK) attests, the interest in green procurement of sustainable textile products for the automotive sector in Europe has not gained enough ground to warrant all or majority of textiles design to be from recycled polyester.

A study of incorporating sustainability into the supply chain management at Volkswagen (J. Koplin et al, 2007) noted essentially two forms of environmental supply management: (1) the integration of environmental criteria/standards into product and production related decisions along the whole supply process (''greening the supply chain''); and (2) the optimisation of the environmental compatibility of purchased goods (''product-based green supply'') (Vermeulen et al, 2011). In the first route, the supplier is evaluated for their environmental performance, achieving and providing certificates for environmental management systems such as ISO 14001 are regarded as minimum qualification criteria for discussions to commence about supplying a product. This supplier in turn will also work with suppliers of their raw materials who have either ISO 14001 or QS-9000 [an automotive standard developed by General Motors, Chrysler and Ford based on ISO 9000]. In the second route, all stages of the lifecycle are considered from packaging, recycling and disposal. The challenge for Sage AI (UK) is to enthuse their client OEM to take up one of these approaches for sustainable interiors textile.

5 Conclusions: Systems approach for sustainable automotive interiors textiles

Figure 7 illustrated the place of Sage AI (UK) in the automotive sector from their perspective. This could also be regarded as the system boundary that the company have for their business. However, from a sustainability perspective, there are a number of issues to be addressed.

5.1 Consumer knowledge

The use of recycled textiles used in production is a dilemma: the recycled polyester is blended with virgin polyester and so the resultant fabric does not look different from the non-recycled fabrics thus raising questions from OEM customers and final vehicle consumers alike about the validity of the sustainable claims and extra costs.

A recent study of sustainable supply chain management within the Indian textile industry noted that it was important to identify the most influential drivers within the region as these enablers were observed to be context based (Diabat et al., 2014) but they also observed that within the automotive sector the customer was a very influential driver to sustainable textile design. As the use of recycled fabrics (and the use of any recyclable textile component) push up the final costs of the car, the consumer has to be interested to buy recycled/sustainable and this is not easy to predict: there is a large interest in the North Americas, but not so much of a concern within Europe. Research conducted by (European Environmental Agency, 2012) identified that in their sample of 1000 men and women in USA, 70% of them felt that sustainability was now a mainstream issue for them and that nine out of ten of these 'green consumers' wanted to know where recycled materials are used and what recycled fiber brands are used in their carsThe decision to use recycled content within the product, therefore rests on cost and questions that need to be addressed by Sage AI (UK) include:

- Is it a 'deal-breaker', ie, would the use of recycled textiles parts secure a sale
- What are the cost implications on the total supply chain
- Does legislation present any advantages in the use of recycled textiles in production

Our interviews found that although Sage AI headquarters did provide worldwide trends information to all locations, there was some concern regarding consumer knowledge about the EU markets; the implications for Sage AI (UK) are most noteable in their ability to persuade the client to work with them towards the most sustainable textiles solutions, rather than achieving lowest cost.

With reference to Meadows (1997) and her nine interventions for influencing and changing systems, the automotive sector already have governmental policy drivers and material stocks and flows in that the technology is currently available for recyclable and sustainable textiles to be developed for the automotive sector. Given the strength of consumer interest in the US for sustainable textiles within the vehicle, it would be interesting to research how the US consumer became engaged with this. Some of the questions raised from this case study are:

- How are the costs of recycled yarns determined?
- How can equality in costs of recycled/virgin yarns be achieved?
- How can/should the sustainability message for recycled textiles be delivered?
- What new technologies may be developed to ensure that end of life considerations can be taken into account when developing laminated textiles for automotive interiors.

Branding and marketing the sustainability qualities of recycled polyester automotive textiles to educate the consumer would seem to be important. This is taking place with some firms currently (eg Ford Focus working with Unifi who supply the recycled fabric Repreve). The reliance on information from the OEM or Sage HQ in the USA also implies lack of knowledge of the local consumer and technologies such as passive RFID tagging (a system already used for logistics within the supply chains in the fashion, food and automotive tyres and parts industries) may be considered to track consumer uptake of the recycled textiles from Sage AI (UK).

5.2 Recyclability

PTC recycled yarns are made from 100% plastic bottles and, the benefits of using post-consumer recycled yarns is the reduction in greenhouse gas emissions, the reduced energy consumption compared to making virgin yarns from raw materials and associated landfill charges and land use for storing waste plastic bottles (Collora, 2012). The benefits are somewhat counterbalanced by the considerations of another supply chain loop; post-consumer yarns are currently 100% from plastic bottles which require collecting and processing into yarns, there are the collection of plastic bottles, cleaning, transportation and storage of bottles before manufacturing processes, raising issues about transparency within this recycling route (European Environmental Agency, 2012).

As well as the yarn composition, the application of textiles within the visible areas of automotives presents a problem regarding sustainability. Between seven to nine million vehicles are disposed of annually in the EU; only 75% of this is recyclable. Textiles form part of the remainder non-recyclable materials (Collora, 2012). Textiles from ELV seating make up about 15% of automotive shredder residue, (ASR – possible to process into vehicular sound proofing insulation and then finally incinerated) (Erth, Gulich, & STFI, 2008).

Seat covering textile is laminated to impart waterproofness, increased abrasion, stain, flame and UV resistance, retro-Reflection properties which the OEM requires testing standards to be achieved. Lamination involves backing onto foam, usually with adhesive. Currently the most cost effective lamination process renders textiles products to be non-recyclable as lamination involves placing adhesives onto the fabric. It is possible to replace adhesive and foam based lamination process with three dimensional knitted or nonwoven textiles products stitch-bonded or needle-punched onto the exterior fabric enabling separation of layers and recyclability. It is expensive and currently in high value cars.

5.3 Transparency and provenance

Sage AI (UK) mainly use polyester to make their consumer facing textiles. They also use a percentage of post-industrial recycled yarns and post-consumer (PTC) recycled yarns blended with virgin yarns. Post-industrial recycled yarn is easier for Sage AI to use as properties and provenance are known on the whole; it is much more difficult to assert the origin and amount of PTC polyester. As the recycled polyester has issues regarding its provenance, third party labelling (which requires verification for any claims being made) may be helpful. Eco-labels incorporating end of life management strategies such as recycling are beginning to be developed within the textiles industry. The Global Recycled Standard by Textile Exchange certifies that a firm produces recycled textiles to set criteria using post or pre-consumer products. The label was originally developed by Control Union Certifications (CU) in 2008 and ownership was passed to Textile Exchange January 1, 2011 (textile exchange 2014). The textiles exchange website identifies up 400 companies as having been certified (textile exchange 2015).

5.4 New links and relationships to be considered

The links for sustainable automotive interiors textiles are illustrated in figure 7. This system may be expanded in a number of areas, as displayed in table 2 and figure 8 to enhance the systems thinking within the design process,

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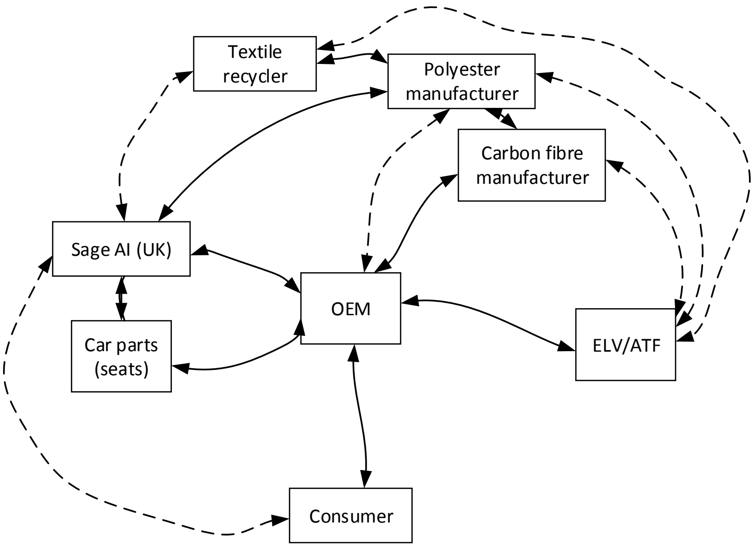
Figure 8: a rudimentary identification of new links for Sage AI (UK) to enhance systems thinking within the design process.



In this diagram, the relationships and inks already present within the design process at Sage is represented by a solid line, new links are represented by the broken lines. Table 2 outlines proposed new links that the literature reviewed has not identified.

Table 2: potential new links for sustainable automotive interiors textile

new links		reason/benefits
textile recycler	ELV/ATF	to develop solutions for the textile, fibres and PU components of the lightweight ASR
	SAGE AI (UK)	to develop non-adhesive laminated textile products for recyclability at end of life
		to develop solutions for waste by-products in their manufacture process
polyester manufacturers and carbon fibre manufacturers	ELV/ATF	better understanding about recyclability and application potential of ASR
	OEM	links with polyester manufacturers to develop branding and marketing of recycled polyester to encourage consumer demand.
consumers/logistics	SAGE AI (UK)	encourage demand for recycled textiles within automotives perhaps through labelleling to track consumer putake patterns in regional areas - to reduce reliance on information from HO in USA and icrease local consumer knowledge

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